An unarmed Minuteman III ICBM is launched out of a silo during a test at Vandenberg Air Force Base, California.
(Photo: U.S. Air Force)

DETONATION

FROM THE BOTTOM UP

Joseph Martz, a technical staff member at Los Alamos since the 1980s, has held a variety of positions during his 20 years in the Lab's Weapons Program. His responsibilities have included leadership of the pit technology group, management of enhanced surveillance in the Stockpile Stewardship Program, leadership of the weapon design division, and project head for the Reliable Replacement Warhead.* **NSS** *asked Martz for his thoughts on stockpile stewardship and its evolution over the last two decades.

Stockpile stewardship is a topic dear to my heart. I've been fascinated by it, and I've lived it—mostly on the technical side but also on the policy side. From 2009 to 2010 at Stanford University, I was a visiting scholar and the inaugural William J. Perry Fellow, working with Perry, former secretary of defense, and Sig Hecker, former Los Alamos Lab director (1986–1997). Together we looked at nuclear deterrence, nuclear policy, and stockpile stewardship and at where all this was headed.

The Nuclear World Changes

In my career, the years from 1989 to 1992 were the most consequential period with respect to nuclear weapons. Three very important things happened during those years, and they led to profound changes in U.S. nuclear policy. First, we had the fall of the Soviet Union, presaged by the fall of the Berlin Wall in 1989. The USSR dissolved on December 25, 1991, and the collapse of the USSR changed everything. The Cold War and its nuclear arms race were over, making an anachronism of MAD [Mutual Assured Destruction], the policy whereby, to deter nuclear war, the United States and the Soviet Union each deployed enough nuclear weapons to ensure the complete destruction of the other.

Second, in 1989 the government halted work at the Rocky Flats Plant, outside of Denver, Colorado, where plutonium pits for primaries [the nuclear triggers for thermonuclear weapons] were produced. That turned out to be a seminal moment in the history of the nuclear weapons complex because, frankly, it ended our ability to produce new weapons and effectively shut down the entire nuclear weapons production complex! Over the next 10 years, more than 50 percent of the historic nuclear weapons complex was shuttered forever.

Third, the Soviet Union had proposed a moratorium on nuclear testing and conducted its last test on October 24, 1990. "Divider," conducted on September 23, 1992, was the United States' last nuclear test. Shortly thereafter a moratorium on testing was legislatively mandated and has been followed by the United States.

The1989 fall of the Berlin Wall was the beginning of the end of the Cold War.
(Photo: Open source)

Any one of those changes would have radically altered how the Lab carried out its national security mission, but all three events together put the Lab in unprecedented territory: instead of *designing and engineering* new weapons for the nuclear stockpile, it would now *maintain* the stockpile. But the cessation of nuclear testing meant the loss of the most important tool the weapons designers had used for 50 years to develop nuclear weapons and to ensure that the stockpile was safe, secure, and reliable.

Between 1989 and 1992, three events put Los Alamos in unprecedented territory.

In addition to closing the factories and putting a moratorium on testing, we'd also agreed not to develop new weapons. That meant we'd lose the means that, along with nuclear testing, had developed and maintained the skills of weapons designers: the continued design and production of new, upgraded nuclear weapons. However, maintaining the designers' skills is vital because although the Cold War is over, shifts in global politics have engendered new national security needs such as protecting the weapons with enhanced security measures in the post-9/11 world. How were we going to manage an aging stockpile and remain agile in the face of changing national security needs?

Inventing "Science-Based" Stewardship

After the collapse of the Soviet Union, President Bill Clinton commissioned the first Nuclear Posture Review to examine the role of nuclear weapons in a post-Soviet world. This review (and every review since) reaffirmed the continued need for U.S. nuclear deterrence, while also recognizing the changing conditions and constraints in the global security environment. For itself and its allies, the United States would continue to maintain its nuclear stockpile, and nuclear deterrence would remain a central element of our supreme national security posture. But that presented the nuclear weapons laboratories with a huge technical challenge. How could the nuclear weapons labs ensure that nuclear weapons remained safe, secure, and reliable in the absence of nuclear testing?

The question was particularly important because the weapons were going to enter configurations that we had no experience with; that is, because we weren't continuing production, the weapons we had would, by default, age beyond their design life. Could we and our allies rely on these complicated weapons in spite of their aging? We would have to understand how age affected the weapons' performance, safety, and security and do that without any further nuclear testing.

This also meant finding new ways to train next-generation designers without the live tests the first generation had used.

How could we and our allies rely on these aging weapons in the absence of further nuclear testing?

Rethinking Mission "How To's"

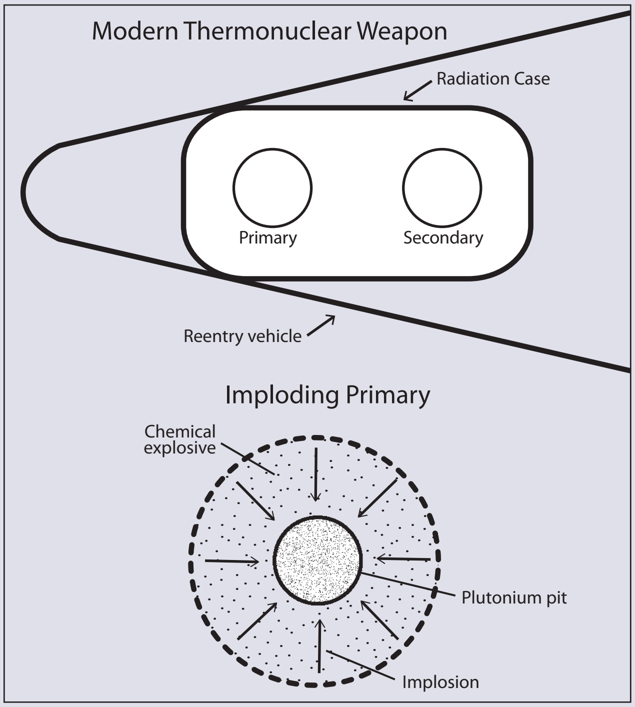
Clearly, we had to rethink the entire problem of meeting our national security mission. Leading that process was Vic Reis, who at that time was assistant secretary for the Department of Energy (DOE) Defense Programs. He would be assisted by the directors of the three DOE weapons laboratories.

The lab directors, with Reis's guidance, convened technical experts from across the DOE weapons complex, and what the experts came up with was the realization that maintaining the stockpile would require an approach that was the complete inverse of the one used during testing. I'll explain what that means.

Continued on p. 6

Nuclear Weapons 101

Nuclear weapons are complex devices operating at the extremes of physics, chemistry, and materials science. The temperature, pressure, velocity, density, and energy produced in a nuclear detonation are essentially unprecedented in human experience. Furthermore, the need to ensure the safety and security of nuclear devices leads to a great paradox: the weapon must be designed to ensure that its exceptional destructive power does not manifest itself when not desired but always does when required. And all the components that produce both results must be designed to fit within a volume and mass of material smaller than a kitchen stove.



A nuclear detonation can be viewed as a series of cascading, compounding events, each of which helps amplify energy production for use in the next main stage. A modern thermonuclear weapon has two main stages: the primary and the secondary. The primary is essentially a fission bomb that releases energy from a runaway fission chain reaction. That energy reaches the secondary, setting it off. The fuel in the secondary undergoes both fission and thermonuclear fusion and releases hundreds to thousands of times more energy than a fission bomb does.

Detonation of a modern thermonuclear weapon begins with an electrical signal to the primary, a signal that is scrupulously controlled to ensure it is transmitted only when there is certainty that a detonation is desired. This signal fires detonators in the primary that ignite a small charge of explosives, which in turn ignites the primary's main charge of explosives. The symmetrical detonation of this main charge is essential for compressing a pit of fissile material—material capable of undergoing nuclear fission—into a supercritical mass. Plutonium and uranium are the fissile materials most often used to make pits. When the pit is compressed into a supercritical mass, a runaway fission chain reaction takes off, generating tremendous amounts of energy very rapidly.

The energy from the primary is manifested as radiation, such as x-ray and neutron radiation. This radiation heats the weapon to temperatures exceeding the temperature of the sun. In modern, two-stage thermonuclear weapons, the primary's radiation is reflected from the radiation case onto the secondary, a component containing both fission and fusion fuels. The tremendous amount of radiation energy absorbed by the secondary creates a crushing shock wave that compresses the secondary into a state that produces vast amounts of fission, fusion, and radiation energy.

The yield from the secondary greatly exceeds what the primary can create. In an atmospheric detonation, the vast amount of radiation energy is absorbed by the air, creating a fireball that emanates thermal radiation and a tremendous shock wave, the sources of the direct damage from a nuclear explosion. Other effects of the nuclear detonation include direct radiation, both x-rays and neutrons, as well as nuclear fallout in the form of fission products.

The Rocky Flats Plant near Denver, Colorado, opened in 1952 to build plutonium pits for primaries, the triggers for thermonuclear weapons. Rocky Flats made thousands of pits per year in a plant with over 300,000 square feet of laboratory space. Pit production was temporarily halted in 1989 and completely discontinued in 1992. (Photo: Open Source)

Continued from p. 4

From the Bottom Up

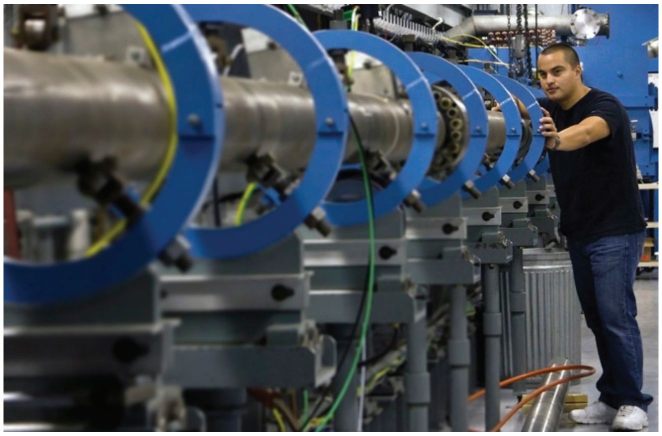
Nuclear testing was a wonderful tool. It was also the world's biggest shortcut. It meant that we didn't have to understand all the details of a nuclear weapon and how it functions. (See "Nuclear Weapons 101.") During the nuclear testing era, we knew enough about how things work and how materials behave to configure a device and make a prediction as to how it would perform. We then detonated it to see if it worked. It usually did, but sometimes it didn't, and we didn't always understand why. Basically, we solved the problem of building safety, security, and reliability into a weapon from the top down: if the full device worked, its components must be working. So we froze the design at this point and did our best to build systems that exactly replicated what we had tested.

> **Stockpile stewardship is all about doing nuclear testing on a computer. It's just damn hard on the computer!**

In the post-testing era, we realized that without the top-down approach, we would have to piece together how nuclear weapons function from the bottom up—that is, gather all the basic science pieces underlying the behavior of each of the weapons' different materials and physical processes and then use that information to calculate how the complete nuclear weapon would function.

We quickly realized the best way to do this was to represent all this basic science as a series of mathematical models and then integrate all those models, along with copious amounts of data about physical properties, into a huge computer calculation that would accurately predict a weapon's performance.

To be sure the calculation was accurate, we would validate it by comparing its results with the data from past U.S. nuclear tests [over 1,000 of them] and the data from newly conducted "integrated" experiments. Integrated experiments reproduce in the real world some portion of how weapons perform, for



A gas gun at Los Alamos sends projectiles into targets at high speeds so scientists can study the properties of plutonium and other weapons materials at high shock pressures, temperatures, and strain rates. (Photo: Los Alamos) example, how some configuration of materials in a warhead behaves when hit by shock waves during detonation. Thus, integrated tests would put real-world checks and balances on our virtual-world calculations of performance.

This was the bottom-up approach. It would enable weapons designers to make technically sound judgments about a weapon's performance without any new nuclear tests. In 1994, shortly after its conception, we named this approach "science-based stockpile stewardship," now the Stockpile Stewardship Program. A colleague of mine, Jas Mercer-Smith, has a good line about this. He likes to say, "Stockpile stewardship is all about doing nuclear testing in a computer. It's just damn hard on the computer!"

Finding the Fundamental Science Pieces

We realized in the early 1990s not only that computer calculations of weapon performance were going to take a level of computing power that didn't exist at the time but also that the basic science pieces for building those computer calculations were missing as well.

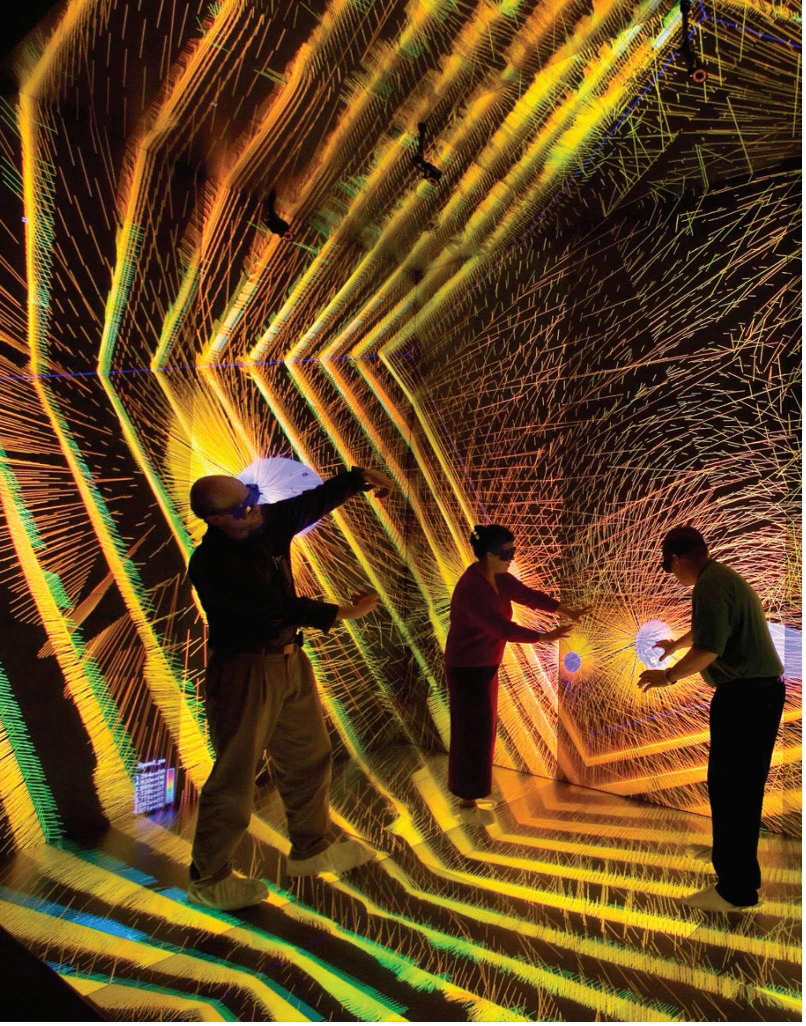
One of the missing science pieces was an understanding of many of the properties of weapon materials—for example, the strength and compressibility of many of the materials within the "physics package" (the energy-producing part of the weapon, containing explosives and fissile material)—and how those properties changed under extreme pressures, temperatures, forces, and accelerations, especially after the materials aged.

In the nuclear testing era, we'd never thoroughly characterized the properties of the materials that went into the weapons—we hadn't needed to because the weapons were tested and regularly replaced. This limited characterization was no more evident than for the most important material in the weapon: plutonium.

For example, we didn't understand the details of how the plutonium sphere [the "pit" inside the primary of a nuclear weapon] gets compressed when its surface is hit by a strong shock wave from high explosives. The pressure from the shock wave causes the plutonium not only to implode [move inward] but also to get denser because the atoms in the plutonium are forced closer together [compressed]. But how much pressure causes how much compression, that is, how great an increase in density?

We needed to put that quantitative information into our computer codes so they could accurately predict exactly when, during implosion, the subcritical pit would reach a supercritical configuration needed to sustain a fission chain reaction. But we didn't have accurate experimental data to give us that quantitative information. Since we didn't know this, we certainly couldn't predict how decades of aging might change plutonium's ability to compress. In fact, we didn't even

The Los Alamos Plutonium Facility opened in 1978 to support nuclear weapons development and testing. After Rocky Flats was shut down in 1992, DOE tasked Los Alamos to begin pit manufacturing. The Los Alamos facility was the only one in the nuclear weapons complex that could be modified to do that kind of work. Compared with the 300,000 square feet at Rocky Flats, the Los alamos Plutonium Facility has only about 60,000 square feet of laboratory space in which Laboratory personnel can conduct almost all the plutonium science and all the pit production in the United States. *(Photo: Los Alamos)*



For stockpile stewardship, Los Alamos scientists use 3D computer visualizations (like the one shown here) to understand the results of weapon performance simulations. (Photo: Los Alamos)

know whether its compressibility, strength, and metallurgical stability actually *would* be affected by aging. So one of the first things we had to do in stewardship was build the tools and facilities needed for measuring these types of material properties in plutonium and in other key weapon materials.

> **During the implosion of a primary, a precise sequence of processes must work together perfectly.**

In 1997 I moved from the group that was charged with examining pits and plutonium, and I asked to start a program to study aging in *all* the materials within the weapon. We called this work "enhanced surveillance." Initially, enhanced surveillance was a $7 million program at Los Alamos, but within a few years, it grew to five times that size. By 1999 we had 40 science projects at Los Alamos, and another 100 projects at other labs and sites, devoted to learning how the various materials would age and how that aging would affect a weapon's performance. Some of the country's best chemists, engineers, and materials scientists became focused on aging nuclear weapons, and the success of their work formed a key basis for the Stockpile Stewardship Program.

Another missing science piece was a detailed quantitative understanding of the other physical processes that go on during a nuclear detonation. (See "Nuclear Weapons 101.")

Through experience and nuclear testing, these processes had been partially measured and modeled, but never to the degree that would make us confident that a bottom-up calculation would be predictive, that is, would provide an accurate picture of exactly how all the processes fit together into a working whole.

To do the basic science experiments needed to improve our understanding of these processes and convert that understanding into mathematical models for high-resolution, 3D, bottom-up calculations of weapon performance, stewardship provided for a number of new research programs. It also provided for new facilities at Los Alamos, Lawrence Livermore, and Sandia National Laboratories. By the year 2000, DOE had established nearly a dozen "campaigns" to address these science issues. These campaigns have made tremendous progress in filling in the gaps in the myriad physics and materials issues of relevance to weapon assessment, and they continue to make advancements to this day.

Accelerated Strategic Computing Initiative

One important campaign was about investing in powerful new scientific computing capabilities—advanced, fast supercomputers and new computer codes—to perform the bottom-up calculations, which would include all the new fundamental science and data from new experiments. In other words, we would take all the new data on material properties, combine those data with the physics we learned, wrap all that into new weapons computer codes millions of lines long and developed over many years and have the codes step through a detonation piece by piece. The codes would mock up the nuclear weapon virtually, first in two dimensions and ultimately in three, using millions of pixels to model the exact shapes of weapon components. And the codes would track the changes in each pixel for many tiny increments of time to accurately simulate the detonation.

In the mid-1990s, a full-system bottom-up calculation—from the detonation of high explosives to the final energy release of the entire warhead—would have had to run for years to reach completion at our newly desired levels of detail. We needed to reduce that running time from years to months, and we needed to do it as soon as possible because most of the weapons designers with testing experience would be retiring over the next decade or two. Their real-life testing experiences would be critical to evaluating the accuracy of the computer models we hoped to generate.

At Nevada we built a state-of-the-art dynamic testing lab down in a mine.

We were running to beat the clock, so Reis, working at DOE, created ASCI, the Accelerated Strategic Computing Initiative. Under that initiative, DOE and the computer industry began producing, at an accelerated pace, computational platforms that started to break records in terms of their capabilities. For example, we reached 1,000 trillion calculations per second (petaflops) in 2008 with the Roadrunner supercomputer, a milestone that was widely considered impossible in the 1990s. Another important advance was the move to parallel processing. Thousands of processors were now used to compute different parts of the same problem simultaneously. These advances increased computational power from millions of calculations per second (megaflops) to trillions (teraflops) and eventually quadrillions (petaflops) of calculations per second. And all this was done to enable the massive calculations that were needed for modeling a nuclear weapon.

Integrated-Test Facilities

But it wasn't enough to have the fundamental data in the new codes and to run the new codes on the new supercomputers. We also needed to validate the predictions from the new codes as correct, so we brought to bear the third major investment for stewardship, namely, facilities where weapons designers, old and new, could do integrated tests that reproduced some but not all aspects of weapon behavior. The real-world results from those integrated tests would provide a check on what the codes predicted for the same phenomena.

The most common integrated test today is, as it was in the testing era, the hydrodynamic test, or "hydrotest," a non-nuclear test in which a replica of a primary undergoes implosion and the implosion is imaged by x-rays. These implosion experiments are called *hydro*dynamic tests because, at the high pressures attained during implosion, the materials flow like liquids. To keep the hydrotest nonnuclear, a surrogate metal is used in place of plutonium.

Hydrotests at DARHT

The most important integrated test facility at Los Alamos is DARHT [pronounced "dart"], the Dual-Axis Radiographic Hydrodynamic Test facility (see p. 41). At DARHT the hydrotest of a mock primary occurs inside a sealed steel test vessel, and two powerful x-ray machines set at a 90-degree angle to each other take simultaneous x-rays of the implosion process, giving us two views at one instant. One of the machines takes a single image, and the other captures a four-image sequence, thereby making a kind of a short "movie."

Continued on p. 11

Down in a mine called U1a, at the Nevada National Security Site, two members of the Los Alamos staff prepare the front end of Cygnus, a powerful x-ray machine similar to DARHT. Two electron beams traverse the two parallel tubular sections (foreground and center) from right to left, are bent, and produce intense x-ray pulses behind the metal wall at the far left. The pulses emerge at a 60-degree angle to each other to record different views of an implosion experiment as in the Gemini experiments (p. 10). (Photo: Los Alamos)

Gemini Experiments

Revolutionary diagnostics at the U1a plutonium laboratory at the Nevada National Security Site (NNSS) have the potential to answer difficult questions about the aging of plutonium, pit manufacturing, features on a pit's surface, and certification of reused pits. In that way, it is possible that they will save billions of dollars in pit production costs.

Those diagnostics were in play during the recent Gemini experiments. Named after the constellation Gemini (the twin brothers Castor and Pollux in Greek mythology), the series consisted of twin hydrotests: scaled-down implosions that test material behavior in a condition similar to that of a weapon primary. The first test, Castor, was designed with a surrogate metal in place of plutonium. Pollux, which used plutonium, is referred to as a subcrit because it did not use enough plutonium to achieve a critical mass. The United States has used the NNSS to execute subcrits as part of stockpile stewardship since 1997.

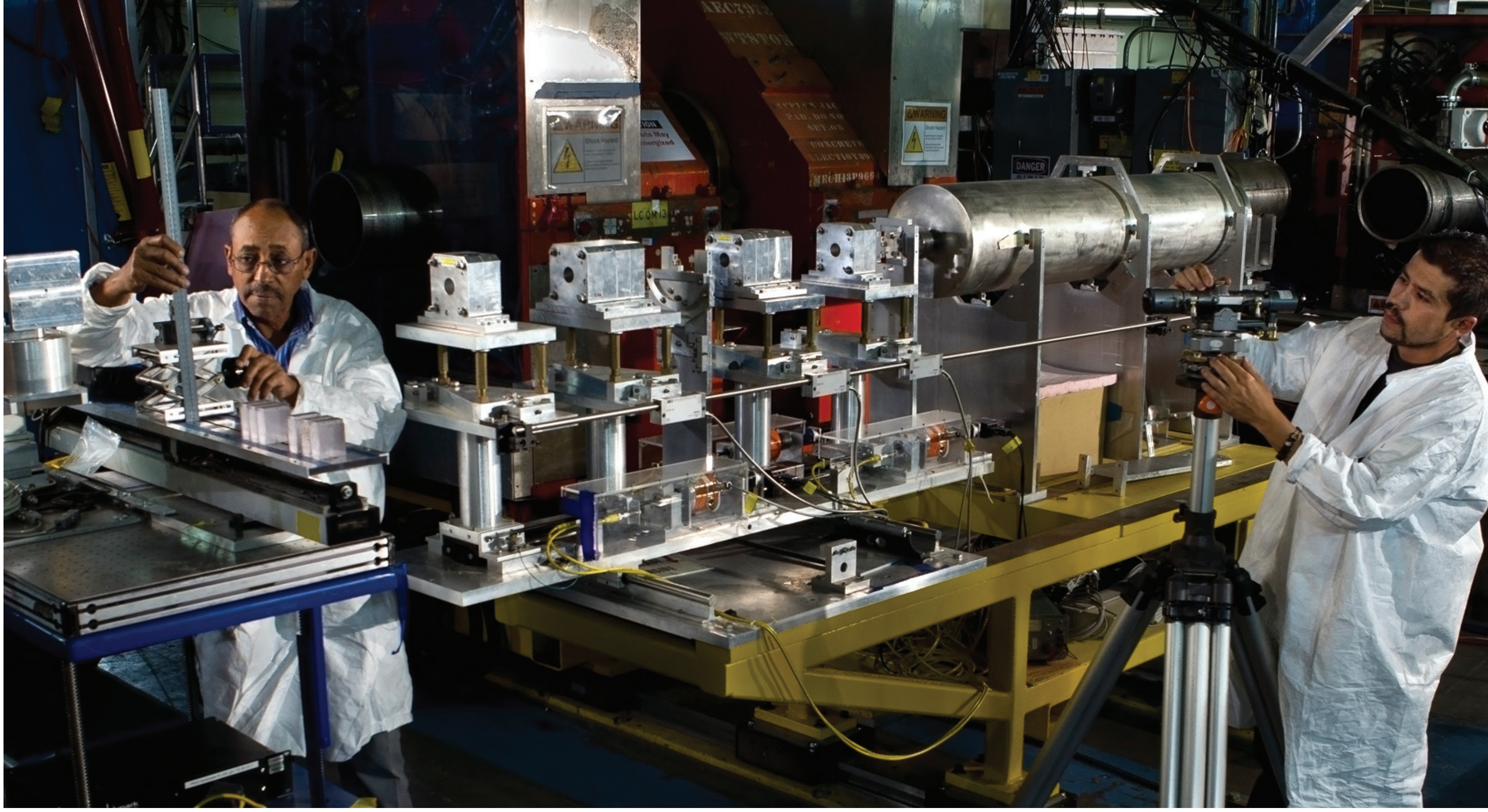
The idea of the Gemini series was to compare the implosion behavior of a surrogate with that of plutonium. The use of surrogate materials is highly desirable—for example, they are less expensive to use, and production is easier. Surrogates are routinely used within the Weapons Program, but we are still studying the limits of their applicability as representatives of plutonium in hydrotests and other experiments. To what extent can experimenting with surrogates tell us how well aged plutonium pits or pits made with new manufacturing processes implode? Do the data obtained from experiments with surrogates contain gaps that affect the data's usefulness for validating the accuracy of the weapons codes? The Gemini experiments could help answer such questions.

The two shots were phenomenally successful. "Diagnostic equipment fielded by our scientists resulted in more data of this kind collected in this single experiment [Pollux] than in all other previous subcritical experiments," says NNSA Deputy Administrator for Defense Programs Don Cook.

"In both Castor and Pollux, the new photon Doppler velocimetry (PDV) diagnostic tool used hundreds of laser beams to continuously monitor the velocity of hundreds of points on the imploding material—all recorded while the material was being driven inward by shock waves from high explosives. PDV produces 10,000 times more data than previous techniques. It is like going from the dots and dashes of the Morse code to high-definition TV. Simultaneously, Cygnus, a powerful x-ray machine (see photo, p. 9), took x-ray snapshots of the implosion from different angles. Used together, x-rays and PDV have the potential to detect effects from aging, processing changes, and features that could impact weapon performance."

Cook continues, "This type of data is critical for ensuring that our computer simulations can accurately predict performance and thus is critical for continuing our confidence in the safety and effectiveness of the nation's stockpile."

In PDV the novel fiber-optic probe shown here measures the velocity distribution of the surface of an imploding pit (not shown) by using hundreds of very thin laser beams. When each laser beam reflects off that surface, its frequency shifts in proportion to the surface velocity at that point. Those shifts made by the different beams thus become a continuous time record of the velocity distribution.



The proton radiography facility at the Los alamos Neutron Science Center, where a powerful proton beam can take "movie" images of a shock wave traveling through high explosives and other weapons materials. (Photo: Los Alamos)

Continued from p. 9

DARHT's images have unprecedented resolution, and we can compare them with our calculations to check whether the calculations simulated the implosion correctly. These capabilities make DARHT a unique experimental facility and critical to the stewardship program because having integrated experimental data for direct comparison with computer simulations is absolutely key to validating our codes and calculations. Lawrence Livermore also developed an important integrated-testing tool at the same time—the National Ignition Facility, NIF. While DARHT concentrates on hydrodynamics in the implosion stage of a primary, NIF is used for studies of later elements of weapon function that are also important to model and understand. DARHT and NIF are used by scientists from each laboratory to gain new understandings of weapons performance and behavior.

> **DARHT is a unique experimental facility and critical to the stewardship program.**

Nevada National Security Site

Because we don't use plutonium at DARHT, we needed to build a facility at the Nevada Test Site [now the Nevada National Security Site] where we could do integrated tests involving plutonium and high explosives. By both executive and congressional order, such experiments would have to be subcritical, "subcrits." These are experiments that dynamically compress plutonium with explosives but must never produce a critical mass.

Over 20 years ago at the Nevada site, a shaft and its supporting network of tunnels were dug 963 feet below the desert surface. This complex, called U1a, was built to contain an underground nuclear test, but the test never took place. Over the last15 years or so, U1a has been expanded and modernized into a highly sophisticated, unique laboratory with advanced diagnostics. Today, U1a is the only place in the nation where high-explosives-driven plutonium testing takes place. Cygnus (see photograph on p. 9), which is akin to a miniature version of DARHT, is an example of an advanced diagnostic at U1a. Cygnus takes x-ray pictures of plutonium as it is explosively imploded.

Recently, in collaboration with National Security Technologies, we added photon Doppler velocimetry, PDV, to our diagnostics. PDV uses hundreds of laser probe beams (see photo on opposite page) to provide substantially more and better data than previously possible, data that is used to better understand the dynamic behavior of nuclear materials.

In essence, we built a state-of-the-art plutonium-testing laboratory in a *mine*, a lab that is revolutionizing our ability to understand and assess how nuclear weapons function. The recent Gemini experiments (see opposite page), which won the prestigious Secretary of Energy Achievement Award, were conducted at U1a.

Proton Radiography

DARHT's x-rays let us take a sequence of four images of the implosion of a surrogate weapon primary. Because it uses strong x-rays, DARHT is very good at imaging dense materials like metals. But many of a weapon's materials (such as explosives, foams, and cushions) aren't dense; they're relatively lightweight. When DARHT is tuned to look for the movement of metals, it can't easily image the movement of shocks in things like high explosives. This problem has been known for many years, and some very clever scientists at Los Alamos figured out that protons—the nuclei of hydrogen atoms—would make an excellent probe to image these lighter materials.

Hence, the science of proton radiography, pRad, was born. The pRad facility, an outgrowth of the Los Alamos Neutron Science Center (LANSCE), uses protons to take images of many of the materials in the physics package at high contrast. Proton radiography is especially well suited to studies of the movement of shock waves inside the explosives themselves. Very short pulses of protons, accelerated to over 80 percent of the speed of light, can penetrate these materials and create a sequence of 10 or more 2D "movie" images of, say, a detonation travelling through high explosives at 17,000 miles per hour.

Weapon Autopsies

An important element of stewardship is a surveillance program to monitor the aging of weapons in the stockpile. Each year the Navy and Air Force return several weapons of each type. Most of these are nondestructively examined and returned to the military. A small number of these weapons undergo destructive evaluation. In essence, we perform an autopsy on them. The weapon is disassembled into its components, and those components are sent back to their production agencies for evaluation. Pits are returned to Los Alamos, where we cut them open for detailed examination. Plutonium is extracted and subjected to a variety of tests to look for aging or for birth defects [flaws created during original manufacture]. These measurements are compared with the manufacturing records for that specific unit, and changes are noted that may have resulted from aging.

> **Cold War weapons were much like Ferraris: complex and lightweight, with high performance but little margin for error.**

During these surveillance operations, if we find a deviation from specifications, we report this as a Significant Finding Notification, or SFN. The designers evaluate each SFN, and if they feel it requires further assessment, they elevate the notification to a Significant Finding Investigation, or SFI.

From 1995 to 2005, the three weapons laboratories opened and investigated a total of 156 SFIs. Of these 156 SFIs, 75 were determined to be "nonactionable." In these 75 cases, the investigation and assessment revealed that no impact on safety, security, or performance was anticipated.

The remaining 81 SFIs were deemed to be actionable, and a component or material was changed, often as part of a scheduled refurbishment process, or a change was made to the certification of the weapon, usually as a limitation in storage, deployment, or military requirements. Using the tools of stewardship and the expert judgment of laboratory staff, these SFIs are being closed. In FY 2013 three SFIs were closed, and to date one SFI has been closed in FY 2014.

Pit Manufacturing

When the Department of Energy closed the Rocky Flats Plant, the facility had not completed enough W88 pits to support destructive surveillance activities. As a consequence, it became apparent that the nation needed to restore its ability to make more pits. That mission was assigned to Los Alamos by then secretary of energy Hazel O'Leary.

U.S. Air Force missileers prepare a Minuteman III intercontinental ballistic missile for a test launch at Vandenberg Air Force Base in California.
(Photo: U.S. Air Force)

This became the pit rebuild program, active from 1997 to 2010. In addition to resupplying pits for the Navy's W88 warheads, pit rebuild had three other important goals. One was to capture some of the manufacturing technologies previously used at Rocky Flats and put them to use at the Lab's Plutonium Facility. The second was to develop replacement technologies for those processes that couldn't be replicated. The third was to demonstrate that we could certify these newly rebuilt pits, along with certain new production methods, using integrated experiments, simulations, and other tools of stewardship.

Rebooting Aged Weapons

It is important to understand the design goals and characteristics of the Cold War–era stockpile, the stockpile we still have today. Weapons designed during the Cold War placed a premium on military characteristics designed to deter a specific adversary, the Soviet Union. One of the design goals was to stretch limited plutonium inventories as far as possible in order to build the most weapons from the limited supply of this strategic material. We were in an arms race with the Soviet Union, and every gram of plutonium mattered. If you could reduce the amount of plutonium in a weapon, you could build a few more weapons.

> **Optimizing yield to weight was everything. This didn't come for free.**

At the same time, we wanted to optimize the yield-to-weight ratio in warheads going onto missiles: we wanted the biggest yield for the least amount of plutonium and in the smallest and lightest warhead package. This allowed the nation to place multiple warheads on a single missile, expanding the target set and enhancing Cold War deterrence. This was especially true for warheads on strategic missiles, where weight was at an absolute premium. Optimizing yield to weight was everything in our designs. This didn't come for free. The price we paid in optimizing lightweight designs for maximum yield was less margin for error and greater complexity—in some cases we made these warheads very complicated. The history of Cold War design at the national laboratories is one of exceptional success; we're very proud of the fact that we did, indeed, build very lightweight, compact, and powerful nuclear weapons. These weapons helped end the Cold War.

But we also didn't leave much margin in the performance of these designs. The margin for error was quite low. In these designs, even something small going wrong can affect the weapon's performance. We often compare weapon designs to sports cars. Cold War weapons were much like Ferraris: complex, high performance, and lightweight, with little margin for error and with costly build and maintenance requirements. And it took not one nuclear test but in some cases up to a dozen to confirm that the highly optimized designs would work under all kinds of environmental and combat conditions. We tweaked these designs between tests to ensure they were operating as we intended, given their tiny margins for error.

Recall that during the Cold War we designed weapons to stay in the stockpile for 10 to maybe 20 years, certainly not 50 or 70 . . . or 100 years. New production and new designs had always replaced older weapons in the stockpile. But all this changed with the period from 1989 to 1992.

The result is that the age of our weapons today requires us to eventually refurbish and "life extend" each warhead. This refurbishment is the work of the life-extension programs (LEPs). The LEPs are designed to refurbish, modify, update, or replace components to ensure that the weapons remain safe, secure, and reliable for an additional 20 to 30 years. The LEPs were executed first for the W87 (a Livermore design) and then for the W76 (a Los Alamos design). The B61 bomb (also a Los Alamos design) LEP is now underway. Eventually, all the weapon types may be "rebooted" in this fashion.

Test launch of a Minuteman III intercontinental ballistic missile at Vandenberg Air Force Base in California. (Photo: Open Source)

The Silent Sentinels

Some people say nuclear weapons aren't that important anymore. In my mind nothing could be further from the truth. I recall a story from a few years ago. During a congressional hearing, a member of the military was asked, basically, what role nuclear weapons still had. Why did we still need them? The answer was, "Nuclear weapons function every day. They are our silent sentinels, reminding everyone of this country's ultimate means of reprisal . . . . Those that would wish ill to the United States must always calculate, have second thoughts, when contemplating an act against us." That's deterrence.

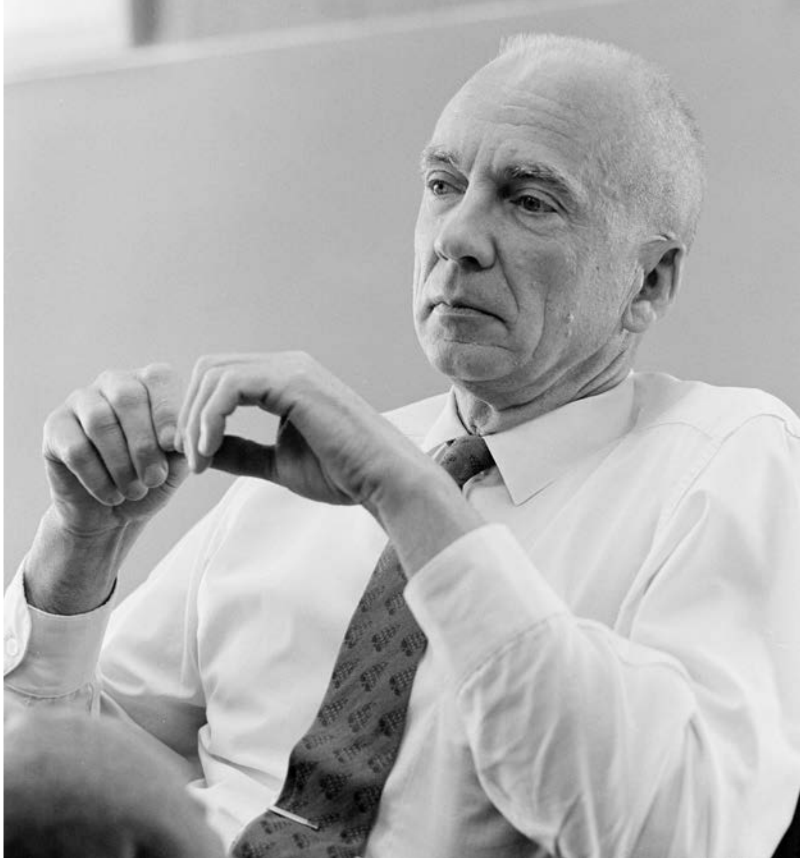
At a deep level, I don't like the fact that we have to threaten retaliation to maintain peace. However, that's the contradiction of deterrence. And from 1945 until today, it hasn't failed. It still operates. Norris Bradbury [the Laboratory's second director] used to call new staff members into his office for a short discussion. He would start by saying, "If the products of our work are ever again used in anger, then we will have failed in our mission. We don't build nuclear weapons to kill people. We build nuclear weapons to buy time for our political leaders to find a better way." Bradbury understood the contradiction of nuclear weapons—that we retain these objects of awful destruction in order to preserve the ultimate peace.

Nuclear weapons have a destructive power that current generations have never witnessed. They've never seen a nuclear weapon tested; it's only in the abstract that they can appreciate the awful power of these creations. Harold Agnew [the Laboratory's third director] proposed that once in every generation a nuclear weapon be detonated above ground, with world leaders required to witness it and see for themselves its sheer size and power. If each generation of leaders did this, they would surely never use a nuclear weapon.

A Better Way

Is there a better way? Can we achieve the benefit of deterrence while lessening the risks? These questions were a few that I examined during my time at Stanford University. I came to understand that the work of Los Alamos and the other weapons laboratories was growing in importance as the country and the world strove to reduce the sheer numbers of nuclear weapons. Indeed, could we find a roadmap to the vision Bradbury had of a better way?

I've come to believe that as stewardship has moved forward, there's been a new kind of payoff. As we become really good at understanding how nuclear weapons work and more confident that we can, with agility, reconstitute an arsenal to respond to new threats, that capability itself becomes a growing part of the deterrent. This is the future. Several prescient Lab staff members predicted this many years ago. Ted Gold and Rich Wagner, in consultation with John Immele, wrote a paper in 1990, "Long Shadows and Virtual Swords," which examined this strategy. The weapons that we designed at Los Alamos are not the sole protectors of our security. The work itself—the science and engineering—is also part of the deterrent. Elements of this strategy, a capability-based deterrent, have been adopted as part of the 2010 Nuclear Posture Review conducted by the Obama administration.



Norris Bradbury, the Laboratory's second director (Photo: Los Alamos)

> **We build nuclear weapons to buy time for our political leaders to find a better way.**

The most important element of stockpile stewardship and a capability-based deterrent is the *people*. I've been a witness to innovations that astound me to this day. The clever ideas, dedication, and work ethic of Los Alamos staff are extraordinary. There have been achievements here in support of stewardship that the previous generation couldn't have imagined. My greatest pride comes from interacting with hundreds of exceptional scientists and engineers at the Laboratory. The challenge in capability-based deterrence is ensuring an agile capability. We must be able to respond to world developments with sufficient agility so that no one doubts our ability to overwhelm and defeat an adversary.

In a very real sense, our deterrent will evolve so that it's not just the products of our work—the nuclear systems we design and maintain—but our work itself that will become the protector of our security. In this vision, the Laboratory is more important than it ever was, and that's where we're headed.

~Joseph Martz